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SPACE VEHICLE SA-3, TELEMETRY SYSTEM

By

W. B. Threlkeld, Jr., and E. H. Reeves, Jr.

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ABSTRACT

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The performance evaluation of the complete telemetry system (ten links) used for flight testing Saturn vehicle SA-3 is presented. The eight operable telemetry links, the two experimental telemetry links, and the telemetry (TM) auxiliary equipment assembly have been technically analyzed on an individual basis.

Statistical analyses were performed on much of the telemetry data and results of these analyses are presented.

No RF signal fade or dropout difficulties were encountered on any of the links.

It is concluded that the overall performance of the telemetry system used for flight testing SA-3 was as anticipated. It is inferred that the derived test data will facilitate the development of more efficient telemetry systems.

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Performance Evaluation Office
Telemetry Systems Branch
Instrumentation and Communication Division
Astrionics Laboratory

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

MTP-ASTR-I-63-17

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SUMMARY

The complete telemetry system consisting of ten telemetry links (eight operational, two experimental) used for flight testing Saturn vehicle SA-3 is analyzed for technical accuracy and adequacy. Each of the ten telemetry links and the TM auxiliary equipment assembly are analyzed on an individual basis and are given separate coverage in this report.

It is concluded that the overall performance of the telemetry system used for flight testing SA-3 was as anticipated. Also, it is inferred that the derived test data will facilitate the development of more efficient telemetry systems.

SECTION I. INTRODUCTION

A. GENERAL

Data transmission for flight testing SA-3 was accomplished by eight telemetry system links and a telemetry (TM) auxiliary equipment assembly (FIG. 2). FIGURE 1 is a block diagram of the SA-3 telemetry system. The links comprising the overall telemetry system were as follows: one XO-4 system, four XO-4B systems, one XO-6C system, two XO-7 systems, one PCM system, and one UHF system.

The composite data handling capacity of the telemetry system was 152 continuous information handling channels and 466 commutated information handling channels.

B. UNSATISFACTORY CONDITION REPORTS

1. Link One. On September 28, 1962, the master pulses of the multiplexer were rounded off. It was determined that this difficulty was caused by a faulty bias battery for the 70 kHz ± 30% subcarrier oscillator. The faulty battery was replaced.

On September 28, 1962, the 14.5 kHz subcarrier oscillator (S/N 17934) had no output. When the output level adjustment was turned, it was found that the output voltage could not be adjusted smoothly. This condition was caused by a broken output level potentiometer. The subcarrier oscillator (S/N 17934) was removed and replaced with an operable subcarrier oscillator (S/N 17933).

2. Link Three. On October 1, 1962, the power amplifier (S/N CC-105) had a low power output (22 watts). The power amplifier (S/N CC-105) was replaced with an operable power amplifier (S/N 39). Investigation showed that the low power output was caused by a weak tube.

3. Link Four. On October 1, 1962, the 1.7 kHz subcarrier oscillator, used with the triple-FM subassembly (22 kHz), had erratic frequency drift. This condition was caused by erratic oscillations in the multivibrator section of the subcarrier oscillator. The subcarrier oscillator (S/N 16265) was removed and replaced with an operable subcarrier oscillator (S/N 161438).

4. Link Ten. On November 14, 1962, the commutator output wave-train had only 12 channels per frame. The commutator (S/N 015) was returned to R-ASTR-IT and it was found that a false trigger was being coupled from the external sync line to the clock network, causing the commutator to omit channels. A modification was performed by the vendor on all commutators of this type; this proved to be a satisfactory solution.

On November 8, 1962, the mixer amplifier (S/N P7334) would deviate the XO-4 transmitter only 5 kHz. Further investigation showed that the mixer amplifier had an output of only .5 volt peak-to-peak. This low output was caused by a weak tube.

5. Spare XO-4B. On October 23, 1962, during lab checkout of telemeter assembly (S/N 6B), it was noted that commutator "A" channel 6 had low amplitude and would vary with the input to channel 5. An investigation revealed that an intermittent short was between the relay contacts for commutator "A," channels 5 and 6. The telemeter assembly (S/N 6B) was returned for repair.

C. TELEMETER SYSTEMS POWER SUPPLY VOLTAGES

Primary power was supplied to the ten systems from the D-11 and D-21 vehicle battery busses. Links 1, 3, 5, 7, and 9 were connected to 28 V dc battery buss D-11. Links 2, 4, 6, 8, and 10 were connected to 28 V dc battery buss D-21.

Flight test measurements were made on the D-11 and D-21 battery buss voltages. The measurement numbers were M17-13 for D-11 (carried on link 3, channel 16, subchannel 13) and M16-13 for D-21 (carried on link 3, channel 16, subchannel 12).

Measuring voltage number 5 failed 2 seconds prior to liftoff; consequently, several measurements were lost. Investigation showed that this failure was probably caused by ignition shock.

SECTION II. TELEMETRY LINKS

A. GENERAL

This section describes and illustrates the ten telemetry links and the auxiliary equipment used; the performance of each is evaluated.

B. LINK ONE

1. XO-6C System (FIG. 3)
Frequency: 242.0 MHz
Data Handling Capacity: 216 commutated channels (96% of availability was utilized) and 13 continuous channels (92% of availability was utilized).

Components: No outboard equipment was used with this system.

Channel Modifications: Connections were added to supply link 6 with the commutator output and timing and control information from this link.

Preflight Calibration: Calibration was applied to the commutated channels from the calibrator located in the multiplexer system. Calibration was applied to the continuous channels from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.

Inflight Calibration: Calibration was applied to the commutated channels from the calibrator located in the multiplexer system. Calibration was applied to the continuous channels from the central calibrator located in the TM auxiliary equipment assembly. Four inflight calibrations were performed on this link during the telemetered phase of the flight test. All calibrations proved to be satisfactory.

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

C. LINK TWO

1. XO-4B System (FIG. 4)

Frequency: 246.3 MHz

Data Handling Capacity: 50 commutated channels (100% of availability was utilized) and 26 continuous channels (100% of availability was utilized).

Components: Two triple-FM outboard subassemblies.

Purpose: The triple-FM outboard subassembly was used to increase channel availability.

Channel Modification: Continuous channels 11 and 12 were modified to accept 7.35 (±7.5%) kHz and 10.5 (±7.5%) kHz, respectively; this modification was accomplished by directly replacing the respective voltage-controlled oscillators with ±7.5% bandpass vibratron filters. Continuous channels 14 and 18 were modified for an input range of -2.5 volts to +2.5 volts to accommodate the ac input signal from the triple-FM subassemblies. Dual mechanical commutators A and B were directly replaced by a solid-state commutator.

Preflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.

Inflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. Four inflight calibrations were performed on this link during the telemetered phase of the flight test. All calibrations proved to be satisfactory.

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of 292 seconds. No RF-signal dropout problems were encountered.

D. LINK THREE

1. XO-4B System (FIG. 5)

Frequency: 248.6 MHz

Data Handling Capacity: 58 commutated channels (100% of availability was utilized) and 25 continuous channels (100% of availability was utilized).

Components: Two triple-FM subassemblies and commutator C (an 8-channel solid-state multiplexer located in the TM auxiliary equipment assembly).

Purpose: Commutator C time-shared 8 channels of flow rate data on channel 10 at a rate of 1 second per channel. Refer to link 2 for the purpose of the triple-FM outboard subassemblies.

Channel Modifications: Identical to link 2.

Preflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.

Inflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. Four inflight calibrations were performed on this link during the telemetered phase of the flight test. All calibrations proved to be satisfactory.

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

E. LINK FOUR

1. XO-4B System (FIG. 6)

Frequency: 249.9 MHz

Data Handling Capacity: 58 commutated channels (81% of availability was utilized) and 25 continuous channels (100% of availability was utilized).

Components: Identical to link 3.

Modifications: Identical to link 2.

Preflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.

Inflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. Four inflight calibrations were performed on this link during the telemetered phase of the flight test. All calibrations proved to be satisfactory.

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

F. LINK FIVE

1. XO-4B System (FIG. 7)

Frequency: 252.4 MHz

Data Handling Capacity: 50 commutated channels (96% of availability was utilized) and 19 continuous channels (100% of availability was utilized).

Components: Triple-FM subassembly

Purpose: Refer to link 2 for purpose of this triple-FM subassembly.

Modifications: Channels 11 and 12 (same as link 2). Channel 14 (same as link 2). The package containing dual mechanical commutator A and B was directly replaced by 2 single solid-state commutators.

Preflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.

Inflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. Four inflight calibrations were performed on this link during the telemetered phase of the flight test. All calibrations proved to be satisfactory.

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

G. LINK SIX (EXPERIMENTAL)

1. PCM System (FIG. 8)
Frequency: 253.8 MHz
Data Handling Capacity: The system received the commutator output of link 1. The system also received digital information from the horizon sensor which was inserted in place of channel 10 of the link 1 commutator.
Components: No outboard equipment was used with this system.
Channel Modifications: None
Preflight Calibration: Received from link 1.
Inflight Calibration: Received from link 1.

Since this was the first flight test of the PCM system, link 6 received the link 1 commutator output (PAM) to allow a comparison to be made between the two systems.

The PCM system received the output wavetrain of the link 1 commutator (300 x 12) and digital information from the horizon sensor. The function of this system was to convert multiplexed analog information to digital information. The system contained an analog-to-digital converter, a programer, and an FM transmitter.

The commutator wavetrain was applied to the A-D converter which changed the analog information to digital information in the form of a serial, binary-coded NRZ space wavetrain.

The programer received timing information from the link 1 commutator and supplied the A-D converter with this information at the proper time; this caused proper formating of the binary-coded wavetrain. The programer presented (to the A-D converter) information from the horizon sensor. The serial, binary-coded wavetrain output of the A-D converter is used to frequency modulate the transmitter.

2. Overall Performance. See Appendix A.

H. LINK SEVEN

1. XO-7 System (FIG. 9)
Frequency: 256.2 MHz
Data Handling Capacity: 4 commutated channels (100% of availability was utilized) and 14 continuous channels (100% of availability was utilized).

Components: Commutator D (a 4-channel solid-state multiplexer located in the TM auxiliary equipment assembly).

Purpose: Commutator D time-shared 4 channels of vibration data on channel 18 at a rate of 3.3 seconds per channel.

Channel Modifications: None

Preflight Calibration: Calibration was applied to this link from the swept-frequency calibrator located in the ground support equipment rack beneath the firing pad. The calibration consisted of a swept-frequency sine wave starting at 3 kHz, proceeding to 0 Hz, and increasing to 150 Hz over a period of 10 seconds. The preflight calibration established a 2-volt peak-to-peak signal that is used for a reference when it is demodulated in the ground receiving equipment. This calibration proved to be satisfactory.

Inflight Calibration: None

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

I. LINK EIGHT

1. XO-7 System (FIG. 9)

Frequency: 259.7 MHz
Data Handling Capacity: See link 7
Components: See link 7
Channel Modifications: None
Preflight Calibration: See link 7
Inflight Calibration: See link 7

2. Overall Performance. The performance of this link was satisfactory. Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

J. LINK NINE (EXPERIMENTAL)

1. UHF System (FIG. 10)

The UHF RF assembly received and was modulated by the modulation output of the link 10 mixer amplifier. The assembly consists of an automatic frequency stabilizer, UHF oscillator, crystal oscillator, buffer amplifier, drive amplifier, and an RF power amplifier with an output of 10 watts.

The purpose of the UHF system was to investigate RF transmission of a PAM/FM/FM modulated signal at UHF frequencies. Because of the redundancy of the UHF system modulation with the modulation of link 10, an excellent basis for comparison of UHF and VHF transmission frequencies exists. Another purpose of the UHF system was to subject a state-of-the-art UHF transmitter assembly to a flight test environment.

Frequency: 2287 MHz
Data Handling Capacity: Redundant to link 10

Since this was the first flight test of the UHF system, link 9 received the mixer-amplifier output of link 10 to allow a comparison to be made between the systems (Appendix B).

2. Overall Performance. The performance of this link was satisfactory, as evidenced by the data received (Table VI). Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF-signal dropout problems were encountered.

K. LINK TEN

1. XO-4 System (FIG. 11)
Frequency: 258.5 MHz
Data Handling Capacity: 25 commutated channels (96% of availability was utilized) and 16 continuous channels (100% of availability was utilized).
Components: No outboard equipment was used with this system.
Channel Modifications: Connection was added to supply link 9 with the mixer-amplifier output.
Preflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.
Inflight Calibration: Calibration was applied to this link from the central calibrator located in the TM auxiliary equipment assembly. This calibration proved to be satisfactory.

2. Overall Performance. The performance of this link was satisfactory, as evidenced by the data received (Table VII). Transmitted RF power was sufficient to produce good data during a flight time of + 292 seconds. No RF signal dropout problems were encountered.

L. TM AUXILIARY EQUIPMENT ASSEMBLY (FIG. 2)

The TM auxiliary equipment assembly was a modular package used to group the auxiliary components of the various links into one assembly. It consisted of two 4-channel vibration multiplexers, two 8-channel flowrate multiplexers, and a central calibrator. The performance of this assembly was satisfactory with no deviation from normal operation.

M. RF POWER

Table I shows the results of RF power tests performed on the S-I stage telemetry systems at LVO by the Telemetry Field Section. The RF power was measured at the input and at the output of the various multicouplers.

TABLE I. RESULTS OF RF POWER TESTS PERFORMED ON SA-3, S-I STAGE TELEMETRY SYSTEMS AT LVO BY THE TELEMETRY FIELD SECTION.

Telemetry Link	Frequency (MHz)	Input RF Power Level to Multicoupler (Watts)	Output RF Power Level from Multicoupler (Watts)
1	242.0	30.0	22.0
2	246.3	32.0	21.0
3	248.6	31.5	22.0
4	249.9	33.0	21.0
5	252.4	29.5	22.5
6	253.8	4.5	2.9
7	256.2	28.5	24.0
8	259.7	27.5	18.5
9	2287.0	7.5	No multicoupler used
10	258.5	32.5	No multicoupler used

APPENDIX A

ANALYSIS AND COMPARISON OF MULTIPLEXED DATA AS DERIVED FROM PAM/FM/FM LINK 1 AND EXPERIMENTAL PCM/FM LINK 6

Data obtained from the SA-3 flight test by means of the 216 channel multiplexer were handled redundantly from the output of the multiplexer through the PAM/FM/FM link 1 system(FIG. 3) and through the PCM/FM link 6 system(FIG. 8) (except for the inserted digital data which were carried exclusively by the PCM/FM link). Two hundred and seven multiplexed channels were carried in redundancy by the two links. The sampling rate per channel was 12 samples per second; 216 of the multiplexed channels for the PAM/FM/FM link were inflight calibrated and 207 for the PCM/FM were inflight calibrated. Four inflight calibrations were given by the 216 channel multiplexer during the SA-3 flight test. An inflight calibration is generated by the inflight calibrator section (FIG. 12) of the 216 channel multiplexer and derived in the calibrator by applying a 5.00 volts dc level from the D-89 master measuring voltage buss to a 400 ohm series precision resistor voltage divider. The output of the calibrator is in the form of five sequential voltage levels: 0.0%, 25.0%, 50.0%, 75.0%, and 100.0% of the D-89 buss voltage level (5.00 volts dc). Each level is synchronized to, and maintained for, one master frame of the 216 channel multiplexer. The calibrator output is inserted into the multiplexer wavetrain as shown in FIGURE 12. Each inflight calibration gives one sample per calibrator output level for each multiplexer channel for the point in time at which the calibration cycle is executed.

An inflight calibration transmitted through a system to the data reduction output will serve as an indication of:

1. The data acquisition system nonlinearity from the calibration insertion point to the data reduction output.

2. Bias effects within the calibrated portion of the system as a function of time.

3. Sensitivity change versus time for the calibrated portion of the system.

4. The amount of variance or "scatter" of the data channels as a function of time.

Several analyses were made of the four inflight calibrations transmitted by link 6 (PCM) and link 1 (PAM) redundantly during the SA-3 flight test.

The summarized data consisting of the mean and standard deviation for both the PCM and PAM links are presented in Tables II and III, respectively.

ANOVA ANALYSES

PCM Link Analysis

A two-way ANOVA with replication for individual multiplexed outputs of the PCM link (assuming the levels to be "fixed" and the calibrations random) is presented in Table IV. In general, the findings of this analysis are as follows:

(a) Effects between the four calibrations were significant at the 1% level of significance; i.e., the means of the calibrations differed from one calibration period to the next.

(b) The calibration-by-level interaction was not significant; i.e., within a specific calibration level, from one calibration period to the next, there is no significant difference between the variances.

(c) Estimates of the components of variance are:

1. Calibrations = .129
2. Experimental = 1.370
3. Total = 110,698.00

PAM Analysis

Table V presents a two-way mixed ANOVA for individual multiplexed outputs of the PAM link. Again, calibrations have been assumed random and input levels fixed. In general, the findings of this analysis are as follows:

(a) Effects between the four calibrations were not significantly different. This indicates that the means of the calibrations did not change from one calibration period to the next.

TABLE II. SA-3 FLIGHT CALIBRATION PCM LINK

Inflight Calibration Sequence		Input Calibration Level					0 Reference Channel
		0%	25%	50%	75%	100%	
1	$\bar{X}$	16.739***	249.294*	483.260**	720.367*	957.135*	11.27
	σ^2	1.64	1.19	1.25	1.39	2.16	14.21
	σ	1.28	1.10	1.12	1.18	1.47	3.77
2	$\bar{X}$	17.405***	250.067*	484.212*	721.338*	958.062**	11.70
	σ^2	1.49	1.14	0.98	1.22	1.77	14.45
	σ	1.22	1.07	0.99	1.11	1.33	3.80
3	$\bar{X}$	16.806***	249.555*	483.647*	720.657**	957.391**	11.23
	σ^2	1.36	1.06	0.99	1.12	1.92	14.19
	σ	1.17	1.03	0.99	1.06	1.39	3.77
4	$\bar{X}$	16.869***	249.618*	483.705*	720.748*	957.579*	11.26
	σ^2	1.33	1.06	0.94	1.31	1.83	14.38
	σ	1.15	1.03	0.97	1.14	1.36	3.79

* Normally Distributed
** Moderately Non-Normal Distribution
*** Significantly Non-Normal Distribition

TABLE III. SA-3 FLIGHT CALIBRATION PAM LINK

Inflight Calibration Sequence		Input Calibration Level				
		0%	25%	50%	75%	100%
1	$\overline{X}$	-423.148	-91.023	243.130	587.023	926.056
	σ^2	68.233	46.786	39.119	62.716	144.130
	σ	8.260	6.840	6.255	7.919	12.005
2	$\overline{X}$	-425.157	-91.866	243.222	585.991	925.551
	σ^2	68.556	52.005	36.053	56.042	125.470
	σ	8.280	7.211	6.004	7.486	11.201
3	$\overline{X}$	-423.736	-91.764	242.611	585.597	924.917
	σ^2	73.733	40.563	37.998	74.153	135.377
	σ	8.587	6.369	6.164	8.611	11.635
4	$\overline{X}$	-425.380	-91.625	243.880	588.241	926.657
	σ^2	115.070	101.566	90.563	70.405	127.842
	σ	10.727	10.078	9.516	8.391	11.307

TABLE IV. TWO-WAY ANOVA WITH REPLICATION FOR INDIVIDUAL MULTIPLEXED OUTPUTS OF PCM LINK, SA-3. ASSUMPTIONS: TIME OF OCCURRENCE OF CALIBRATIONS RANDOM, LEVELS FIXED

Source	Sum of Squares	Degrees of Freedom	Mean Square	Var. Ratio
Calibration	404	3	$S_2^2 =$ 134.67	$S_2^2/S_e^2 = 98.30$**
Level	458,173,420	4	$S_1^2 =$ 114,543,355.00	
Cal. X Level	13	12	$S_3^2 =$ 1.08	$S_3^2/S_e^2 =$ 78
Exp. Error	5,640	4,120	$S_e^2 =$ 1.37	
Total	458,179,477	4,139		

** Significantly Different at .01 Level of Significance

$F_{.01}(3, \infty) = 3.78$

$F_{.01}(12, \infty) = 2.18$

TABLE V. TWO-WAY ANOVA WITH REPLICATION FOR INDIVIDUAL MULTIPLEXED OUTPUTS OF PAM LINK, SA-3. ASSUMPTIONS: CALIBRATIONS RANDOM, LEVELS FIXED

Source	Sum of Squares	Degrees of Freedom	Mean Square	Var. Ratio
Calibration	338	3	$S_2^2 =$ 113.00	$S_2^2/S_e^2 = 1.43$
Level	986,276,937	4	$S_1^2 =$ 246,569,234.00	
Cal. X Level	2,204	12	$S_3^2 =$ 183.00	$S_3^2/S_e^2 = 2.31$**
Exp. Error	338,256	4300	$S_e^2 =$ 79.00	
Total	986,617,735	4319		

** Significantly Different at .01 Level of Significance

$F_{.01}(3, \infty) = 3.78$

$F_{.01}(12, \infty) = 2.18$

(b) There was a significant calibration-by-level interaction at the 1% level of significance; i. e., within a specific calibration level, from one calibration period to the next, there is a significant difference between the variances.

(c) Estimates of the components of variance are:

1. Calibration-by-level = .39

2. Experimental error = 79

3. Total = 228,436

PCM Link versus PAM Link

An average scale range of 940 digitized units was used for the PCM link, and an average scale range of 1350 digitized units was used for the PAM link. Consequently, the PAM link scale was adjusted to the length used for the PCM link to permit a direct comparison of the two links. This scale adjustment was made for each calibration period.

A paired comparison of the mean digitized unit output for the 25%, 50%, and 75% input levels indicated that the links were not significantly different at the 5% level of significance. The 0% and 100% input levels were not included in this analysis since the change in scale by necessity made them equal.

A comparison of the experimental errors of the two links indicates that the PAM link is much noisier than the PCM link. The PAM experimental error reduces to 7.41 digitized units after scale change. As compared to the PCM experimental error of 1.17 digitized units, the PAM link is 533% noisier. Another meaningful comparison is that 99% of the time, PAM noise would be expected to be ± 1.97% of its scale length and PCM noise to be ± .37% of its scale length.

BARTLETT ANALYSIS

A statistical study was made of the inflight calibrations applied to the PAM and PCM systems. Four inflight calibrations were applied to the systems during the flight test period. There were 207 calibrated channels in the PCM system and 216 calibrated channels in the PAM system. Each group of channels was examined separately for the purpose of this statistical study. Each calibration level (0%, 25%, 50%, 75%, and 100%) constituted a sample; there were four calibrations of five calibration levels each, for a total of twenty samples.

The mean, variance, and standard deviation was calculated for each sample (Tables II and III). The calculations were performed as shown below:

$$\bar{X} = \frac{\sum_{i=1}^{N} Xi}{N}$$

$$\sigma^2 = \frac{\sum_{i=1}^{N} (Xi)^2}{N} - (\bar{X})^2$$

$$\sigma = \sqrt{\sigma^2}$$

where: $\bar{X}$ = mean
σ^2 = variance
σ = standard deviation
N = number of readings chosen for each calibration level
X_i = individual readings of each calibration level

A statistical test (Bartlett's test) was performed to determine if the variability of the samples was constant or if some samples showed significantly greater variability than others (using a confidence level of 95%). The calculations for Bartlett's test were performed as shown below:

$$M = 2 \cdot 3026 \left[N \log \frac{\sum_{i=1}^{g} NiVi}{N} - \sum_{i=1}^{g} Ni \log Vi \right]$$

$$C = 1 + \frac{1}{3(g-1)} \left[\sum_{i=1}^{g} \frac{1}{Ni} - \frac{1}{N} \right]$$

where:

$m/_c$ = ratio to be compared with 95% confidence level of the chi-square distribution

g = number of samples

Ni = number of readings per sample minus one

$$N = \sum_{i=1}^{g} Ni$$

Vi = individual variances of each sample

PCM/

First: Bartlett's test was performed on all 20 samples; significant differences were found between the variances at a 95% confidence level.

Second: It was thought that the differences may have been caused by the variability of the normality of the samples. A chi-square test (confidence level of 95%) was performed to determine if each sample had a normal distribution. It was found that 12 of the 20 samples had normal distributions (Table II). Note that all 25% levels followed normal distributions and that all 0% levels did not follow normal distributions. Also, the 0% levels were significantly non-normal, while the remaining non-normals were only moderately non-normal (using 95% confidence levels in all cases). If a 90% confidence level had been used, the moderately non-normals could possibly have been considered normal.

Third: The test was performed on the 12 normal samples; significant differences were noted between the variances at a 95% confidence level.

Fourth: The five levels of each calibration were tested separately (e.g., calibration 1 at 0%, 25%, 50%, 75% and 100%); significant differences were found between these variances at a 95% confidence level.

Fifth: The test was performed on the same levels of each calibration (e.g., 0% for calibrations 1, 2, 3, and 4); no significant difference existed between these variances at a 95% confidence level.

Results: It is concluded that the variability between calibration levels for a particular calibration is not constant; but the variability for the same calibration level between different calibrations is constant within a 95% confidence level.

Conclusions pertaining to the accuracy of the system were as follows: 68% of the information was within ±0.12% of the mean value, 95% was within ±0.24% of the mean value, and 99% was within ±0.36% of the mean value.

As a matter of future interest, attention is focused to the 0-reference channel. As the calibration level increased from 0% to 100%, the 0-reference decreased in value. This can possibly be attributed to commutator channel crosstalk. This condition contributes to the large variance evidenced in the 0-reference channel data contained in Table II. Bartlett's test was performed on the variances (using a 95% confidence level), and they were found to be constant between calibrations.

PAM/

First: Bartlett's test was performed on the five levels of each calibration separately (e.g., calibration 1 at 0%, 25%, 50%, 75%, and 100%). There were significant differences between these variances at a 95% confidence level.

Second: The test was performed on the same levels of each of the four calibrations (e.g., 0% for calibrations 1, 2, 3, and 4). Significant differences were found between these variances at a 95% confidence level.

Third: It was noticed that the fourth calibration variances were larger than the variances for calibrations 1, 2, or 3. Bartlett's test was performed on the same levels of calibrations 1, 2, and 3; it was found that no significant differences existed between these variances at a 95% confidence level.

Conclusions pertaining to the accuracy of the system were as follows: 68% of the information was within ±0.65% of the mean value; 95% was within ±1.30% of the mean value; and 99% was within ±1.95% of the mean value.

APPENDIX B

UHF-VHF ANALYSIS AND COMPARISON OF LINKS 9 AND 10

Several analyses were performed on link 9 (UHF) and link 10 (VHF). Since link 9 was experimental, it transmitted data redundant to link 10. The analyses were performed on channels 2, 3, 4, 5, and 13 of each link for in-flight calibrations 1, 2, and 3. UHF and VHF SA-3 flight test calibration data are presented in Tables VI and VII, respectively.

Bartlett's test was performed to determine if there were significantly different variances as shown below:

LINK 9

1. Analysis of variances within the same calibration level between channels. At a 95% confidence level, significantly different variances were found between channels for the 0%, 50%, and 100% levels.

2. A single variance including all channels calculated for each calibration level. At a 95% confidence level, no significant difference was found between the five calibration levels.

3. Analysis of variances between calibration levels within a single channel. At a 95% confidence level, a significant difference was found between the variances within channels 2 and 3.

4. A single variance including all levels calculated for each channel. At a 95% confidence level, there was no significant difference of the variances between the channels.

LINK 10

1. Analysis of variances within the same calibration level between channels. At a 95% confidence level, significantly different variances were found between channels for the 0% and 75% levels.

2. A single variance including all channels calculated for each calibration level. At a 95% confidence level, no significant difference was found between the five calibrations levels.

TABLE VI. UHF SA-3 FLIGHT TEST CALIBRATION DATA

Channels	Flight Time	0% Cal. Step		25% Cal. Step		50% Cal. Step		75% Cal. Step		100% Cal. Step		% Change Based on First Cal.	
	Seconds	Mean in %	σ in %	Mean in %	σ in %	Mean in %	σ in %	Mean in %	σ in %	Mean in %	σ in %	0% Cal. Step in %	Range in %
2	7.5	0	0.25	23.85	0.32	48.95	0.15	74.63	0.38	100	0.52	-	-
	92.9	0	0.80	23.75	0.32	48.54	0.36	75.11	0.58	100	0.14	+0.31	+0.07
	160.2	0	0.82	24.09	0.23	48.80	0.07	74.44	0.30	100	0.19	+0.11	-0.16
3	7.5	0	0.17	24.27	0.41	49.06	0.52	74.73	0.51	100	0.52	-	-
	92.9	0	0.65	23.26	0.32	48.30	0.36	74.74	0.31	100	0.14	+0.72	+0.71
	160.2	0	0.24	23.61	0.24	48.79	0.07	75.11	0.47	100	0.19	+0.30	-0.35
4	7.5	0	0.58	24.48	0.54	49.19	0.70	74.58	0.70	100	0.43	-	-
	92.9	0	0.42	23.88	0.39	49.03	0.48	74.40	0.32	100	0.40	-0.27	+0.08
	160.2	0	0.59	24.09	0.77	49.09	0.78	74.79	0.75	100	0.56	-0.41	-0.95
5	7.5	0	0.42	24.41	0.43	49.32	0.52	74.71	0.46	100	0.50	-	-
	92.9	0	0.57	24.74	0.51	49.45	0.38	74.84	0.35	100	0.34	+0.65	+0.21
	160.2	0	0.69	24.59	0.66	49.40	0.54	74.85	0.16	100	0.49	+0.06	+0.55
13	7.5	0	0.30	24.08	0.50	49.03	0.78	74.37	0.53	100	0.43	-	-
	92.9	0	0.20	24.24	0.19	49.07	0.58	74.56	0.68	100	0.58	+0.46	+0.11
	160.2	0	0.66	24.74	0.37	49.25	0.31	74.12	0.53	100	0.53	+0.46	-0.01

TABLE VII. VHF SA-3 FLIGHT TEST CALIBRATION DATA

Channels	Flight Time	0% Cal. Step		25% Cal. Step		50% Cal. Step		75% Cal. Step		100% Cal. Step		% Change Based on First Cal.	
	Seconds	Mean in %	σ in %	Mean in %	σ in %	Mean in %	σ in %	Mean in %	σ in %	Mean in %	σ in %	0% Cal. Step in %	Range in %
2	7.5	0	0.05	23.87	0.20	49.15	0.30	74.22	0.23	100	0.54	-	-
	92.9	0	0.45	23.71	0.32	49.35	0.06	74.04	0.50	100	0.18	-0.04	+0.53
	160.2	0	0.26	23.88	0.16	48.78	0.15	74.69	0.23	100	0.34	+0.22	+0.12
3	7.5	0	0.28	24.44	0.22	49.53	0.31	74.42	0.12	100	0.19	-	-
	92.9	0	0.09	24.36	0.27	49.13	0.17	74.40	0.39	100	0.26	-0.19	-0.03
	160.2	0	0.21	24.60	0.25	48.85	0.18	74.72	0.23	100	0.21	+0.22	+0.36
4	7.5	0	0.37	24.51	0.20	49.46	0.18	74.49	0.18	100	0.19	-	-
	92.9	0	0.30	24.38	0.28	49.33	0.08	74.45	0.45	100	0.25	-0.07	-0.25
	160.2	0	0.14	24.37	0.18	49.16	0.10	74.71	0.18	100	0.21	+0.07	-0.25
5	7.5	0	0.33	24.13	0.28	49.56	0.21	74.65	0.25	100	0.24	-	-
	92.9	0	0.42	24.82	0.46	49.62	0.18	74.78	0.28	100	0.19	+0.13	-0.15
	160.2	0	0.18	24.53	0.21	49.43	0.19	74.68	0.14	100	0.29	-0.02	-0.31
13	7.5	0	0.20	24.28	0.22	49.34	0.18	74.51	0.24	100	0.21	-	-
	92.9	0	0.23	24.47	0.24	49.36	0.29	74.44	0.11	100	0.21	+0.14	+0.15
	160.2	0	0.27	25.28	0.24	49.44	0.22	74.56	0.23	100	0.17	+0.74	+0.65

3. Analysis of variances between calibration levels within a single channel. At a 95% confidence level, a significant difference was found between the variances within channels 2 and 4.

4. A single variance including all levels calculated for each channel. At a 95% confidence level, a significant difference was found between the variances of the channels.

Comparison of Links 9 and 10

A variance including all calibration levels for each link was computed for each channel. The variances were compared by individual channels between links using the "F" ratio test. At a 99% confidence level, a significant difference was found between the variances of each channel between links.

A variance was computed for each calibration level, including channels 2, 3, 4, 5, and 13 for each link. The variances were compared by calibration levels between links using the "F" ratio test. At a 99% confidence level, a significant difference was found between the variances of each calibration level between links.

An overall variance was computed for each link, including all calibration levels and channels. The variances were compared using the "F" ratio test. At a 99% confidence level, a significant difference was found between the overall variances of the links.

Based on the overall variance of each link, it can be concluded that with a 99% confidence level, the data are within ±1.52% of the range for the UHF system (link 9) and ±0.76% of the range for the VHF system (link 10).

Table VIII shows the percent peak noise by channels and calibration levels. The values shown are based on a 99% confidence level.

TABLE VIII. PERCENT NOISE BY CHANNELS AND CALIBRATION LEVELS

	Channels				
Link	2	3	4	5	13
9	±0.55	±0.66	±1.00	±0.72	±0.83
10	±0.28	±0.18	±0.17	±0.21	±0.15

	Calibration Level				
Link	0%	25%	50%	75%	100%
9	±0.88	±0.80	±0.78	±0.74	±0.65
10	±0.23	±0.20	±0.13	±0.22	±0.20

TABLE IX. MEASURING VOLTAGE SUPPLIES VARIANCES AND STANDARD DEVIATION

Measuring Voltage Supply Number	Mean	Variance (% of Range)	Standard Deviation (% of Range)
1	971.40	0.59	0.25
2	970.63	0.58	0.25
3	969.51	0.50	0.23
4	970.38	0.55	0.24
6	971.17	0.52	0.24
7	965.49	0.75	0.28
8	972.46	0.56	0.24

APPENDIX C

NETWORK MEASURING CABLING NOISE

To arrive at some estimation of the noise attributed to network measurement cables, an analysis was made using measuring voltage supply flight data obtained by the PCM system.

FIGURE 13 shows the block diagram for the measuring voltage hook-up through the 216 channel commutator and the PCM system. The calibration voltages are derived from the master measuring voltage supply through the commutator calibration gates and the PCM system. There are 8 measuring voltage supplies which are slaved to the master measuring voltage supply. These measuring voltages were carried as inflight measurements through the network cabling to the commutator through the multiplexer gates and the PCM system. As shown in FIGURE 13, the measuring voltages can be obtained from two routes: (1) the 100% calibration level through the calibrator section of the commutator and (2) the measuring voltage supply measurements through the multiplexer section of the commutator.

The symbols shown in parenthesis in FIGURE 13 are the variances attributed to the individual components of the system. Explanations of the symbols are:

V_{MMS} - variance of the master measuring voltage supply.

V_{WC} - variance of the wiring between the master measuring voltage supply and the commutator.

V_{CG} - variance of the calibrator gates.

V_{PCM} - variance of the PCM system.

V_{TC} - total variance of the 100% calibration level route. This value is the variance of calibration 1, 100% level, obtained in Table II.

V_{MS1} thru V_{MS8} - variances of the individual measuring voltage supplies.

V_{WM} - variance of the measurement cabling.

V_{MG} - variance of the multiplexer gates.

V_{TM} - total variance of the measurement route consisting of the combined variances of the measuring voltage supply measurements. A variance was derived for each supply measurement by taking 101 samples of the flight data for each measurement immediately preceding and following the first calibration (Table IX). A Bartlett's analysis was performed on these variances and revealed that no significant differences existed between the variances; therefore, they were combined to give the following overall variance.

$$V_{TM} = \frac{\sum_{i=1}^{8} (Ni-1)\,Vi}{\sum_{i=1}^{8} Ni-K}$$

where: V_i = variance of each individual measuring supply measurement.

N_i = number of samples per measurement.

K = number of variances used.

NOTE: Measuring voltage number 5 was not used since it failed as mentioned earlier.

As shown in FIGURE 13,

$$V_{TC} = V_{MMS} + V_{WC} + V_{CG} + V_{PCM} \quad (1)$$

$$V_{TM} = V_{MS1} + V_{WM} + V_{MG} + V_{PCM} \quad (2)$$

The following assumptions were made:

(a) $V_{MMS} \simeq V_{MS1} \simeq V_{MS2} \cdots \simeq V_{MS8}$: Since each measuring supply was slaved to the master measuring supply, any percent difference between the variances would be negligible.

(b) $V_{WC} << V_{WM}$: The calibrator input impedance is 400 ohms and the multiplexer input impedance is 100 K (impedances as seen by the measuring voltages).

(c) $V_{CG} \simeq V_{MG}$: Since several of the gates in the calibrate mode and the measurement mode are common and the main effect of the gates would be bias effects, the differences would be negligible.

(d) Any variances not mentioned would be common; therefore, the variances would cancel.

Solving for V_{WM}:

equation (1) - equation (2)

$$V_{TC} - V_{TM} = - V_{WM}$$

$$V_{WM} = V_{TM} - V_{TC}$$

$$V_{WM} = 5.47 - 2.16 = 3.31 \text{ digitized counts}$$

$$\text{Std. dev.} = \sqrt{V_{WM}} = \sqrt{3.31} = 1.82 \text{ digitized counts}$$

$$\text{Std. dev. (\% of range)} = \frac{1.82}{940.4} = 0.193\% \text{ of range}$$

$$3 \text{ sigma limits} = 3\ (0.193\%) = 0.58\%$$

Based on the results, it can be concluded that with a 99% confidence level the noise attributed by the measurement cabling was within ±0.58% of the mean.

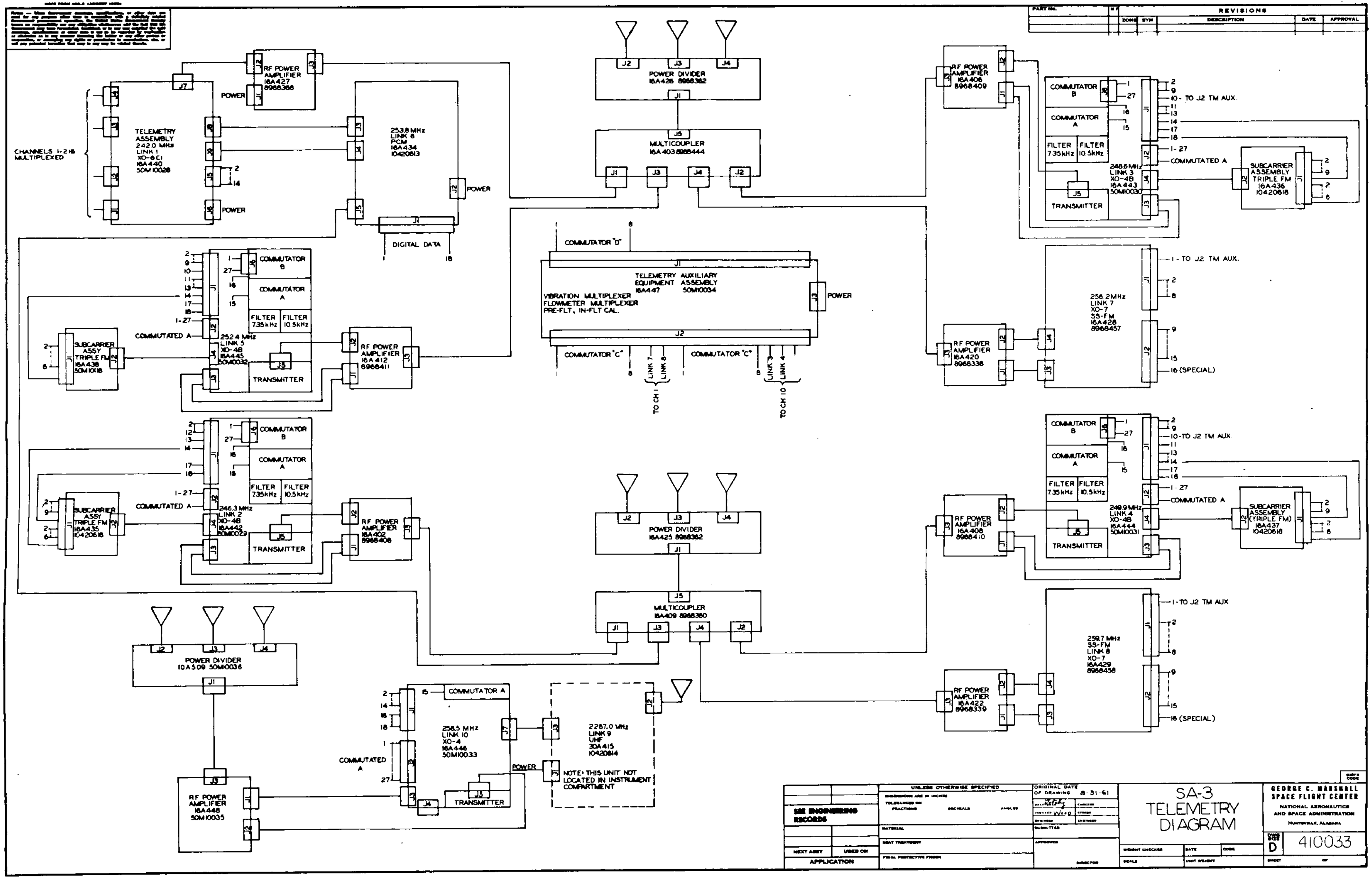

FIGURE 1. SA-3 TELEMETRY DIAGRAM

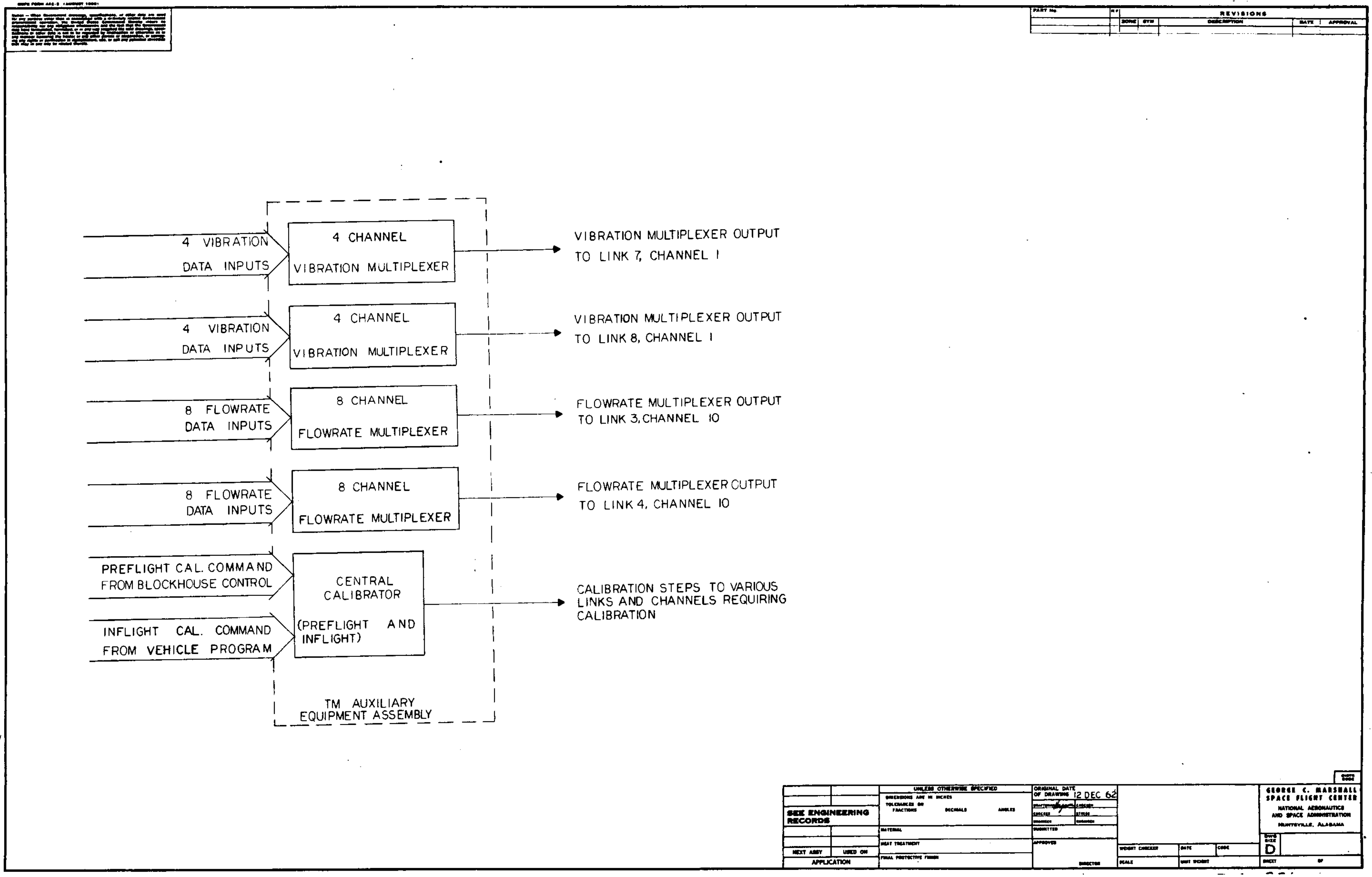

FIGURE 2. BLOCK DIAGRAM OF SA-3 TELEMETRY AUXILIARY EQUIPMENT

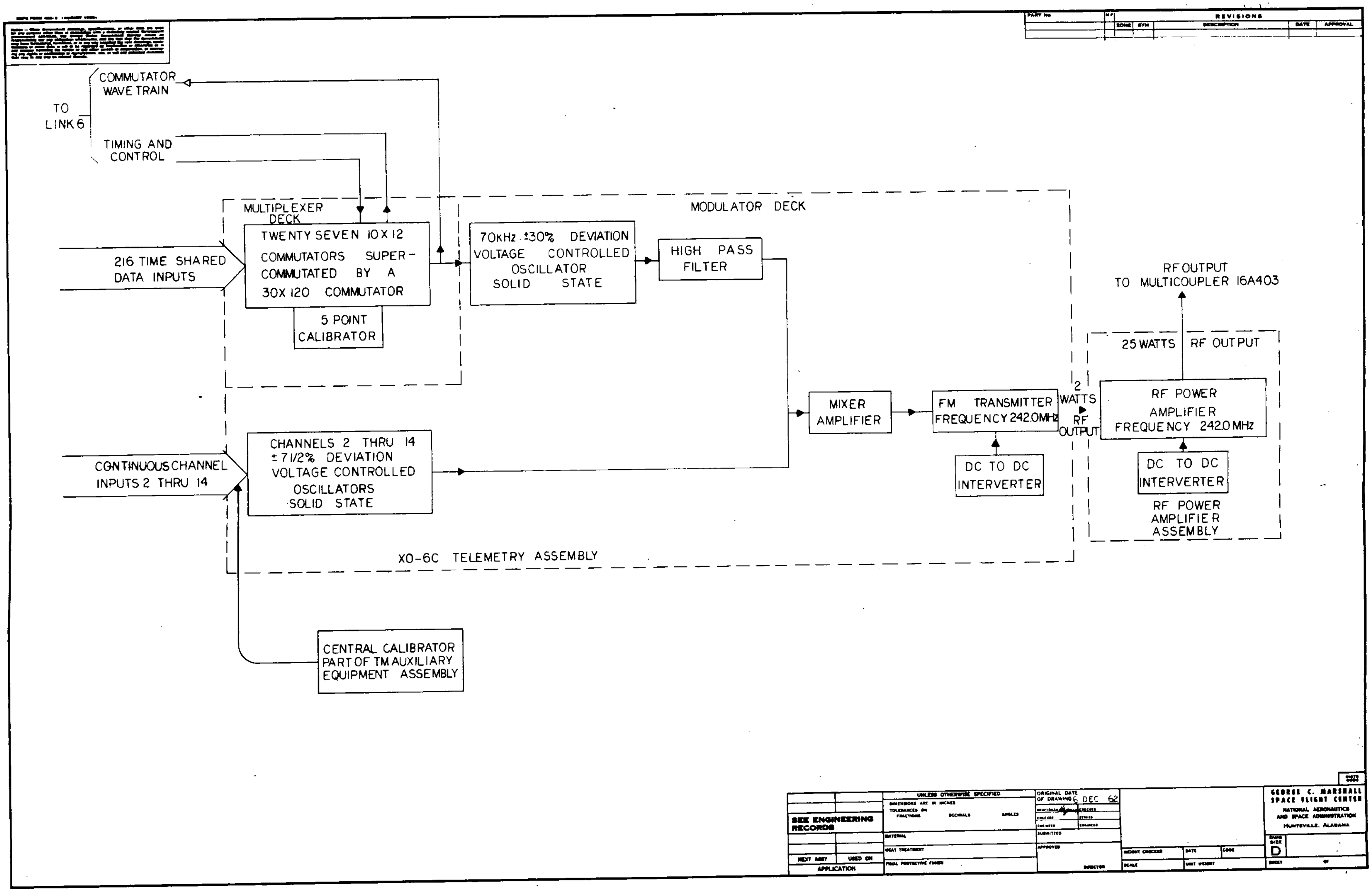

FIGURE 3. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 1

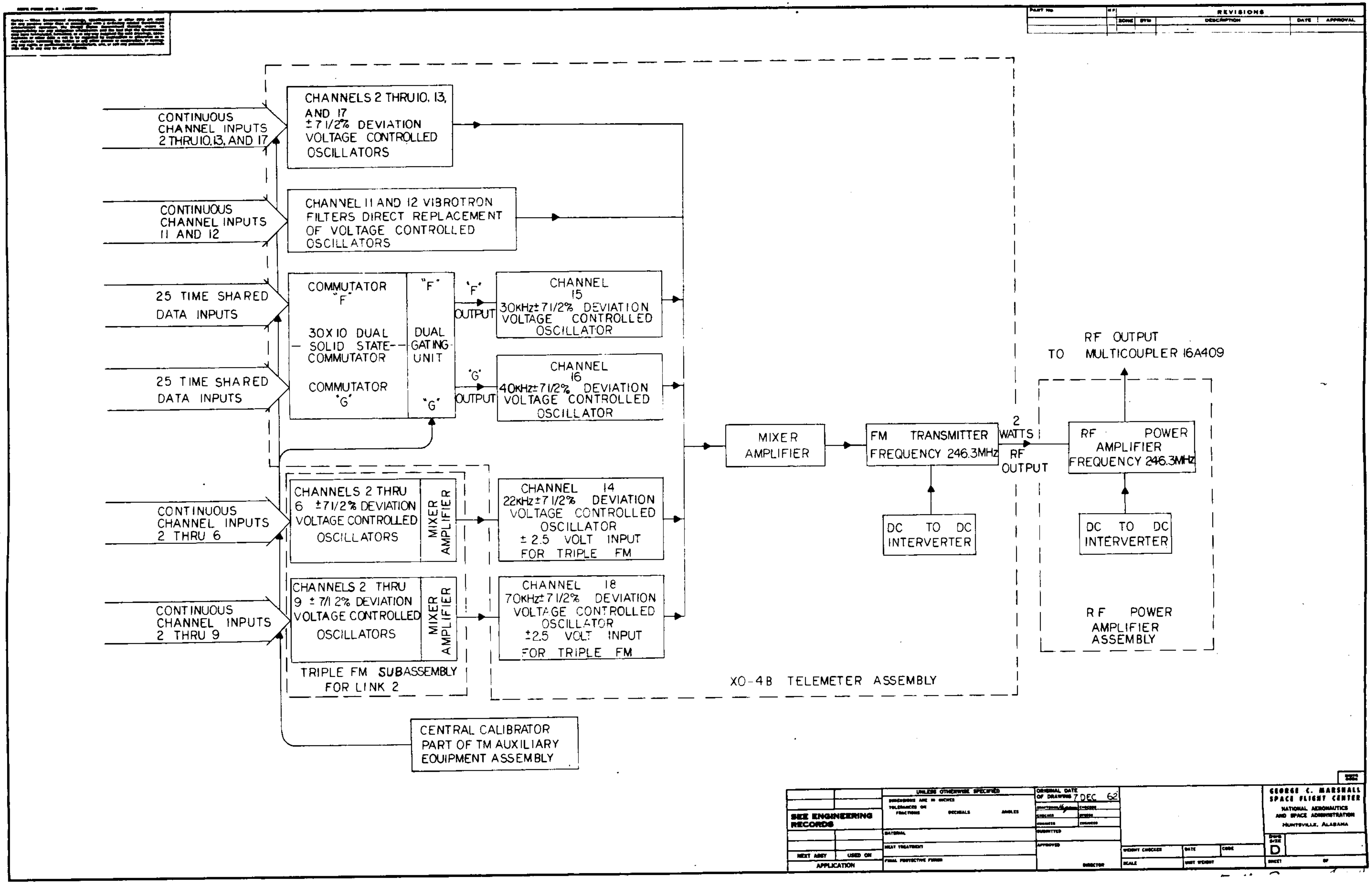

FIGURE 4. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 2

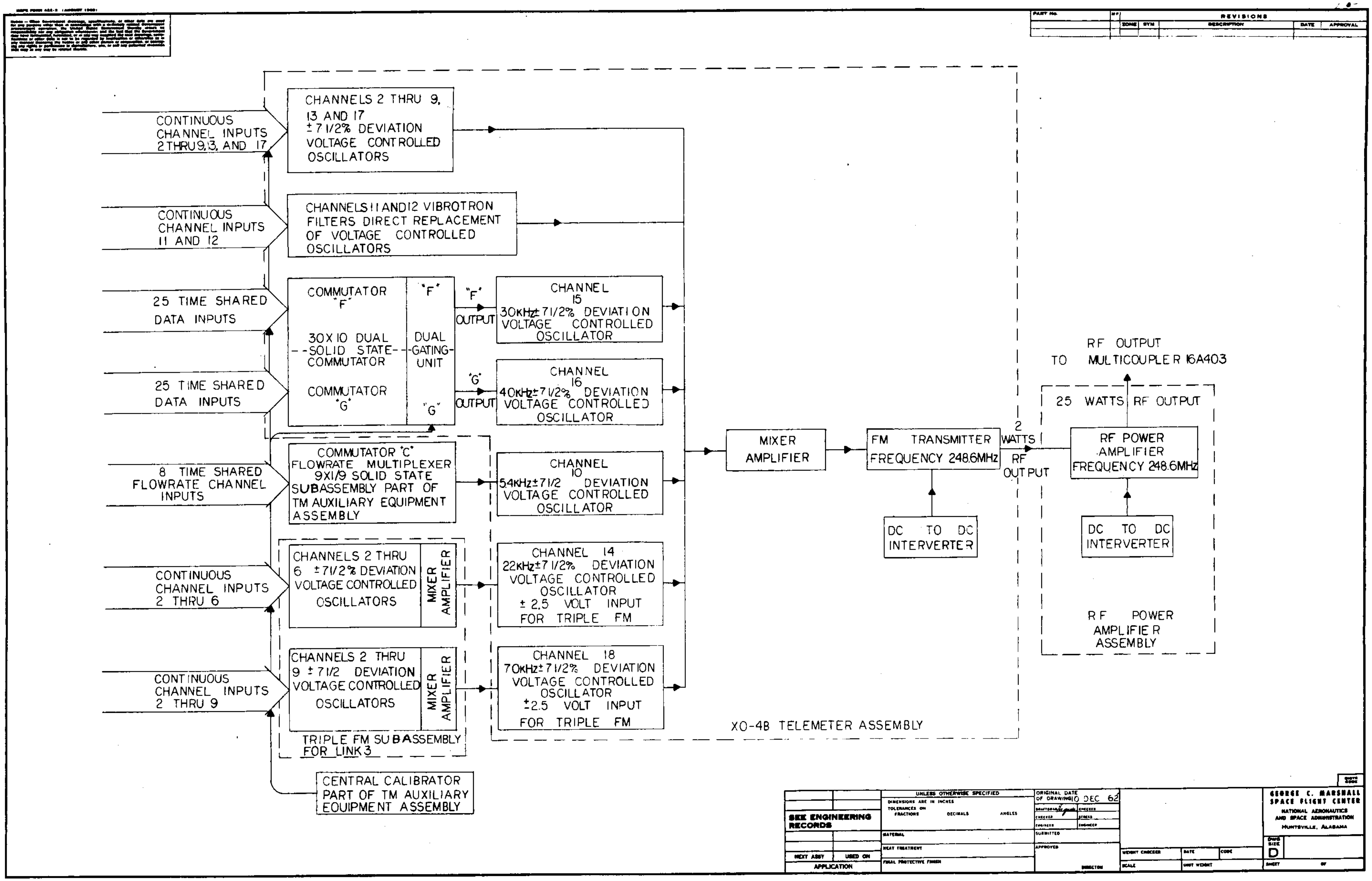

FIGURE 5. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 3

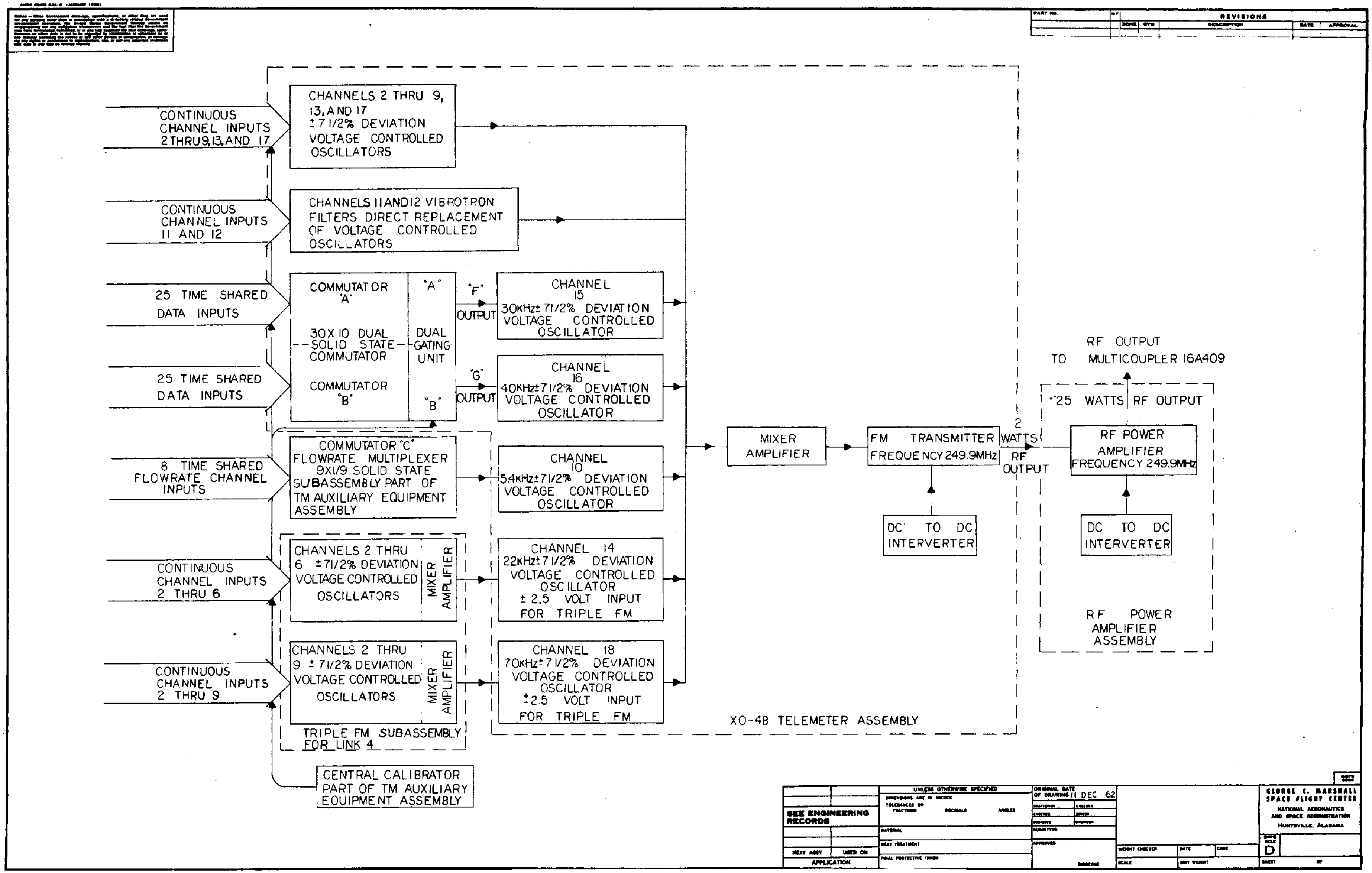

FIGURE 6. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 4

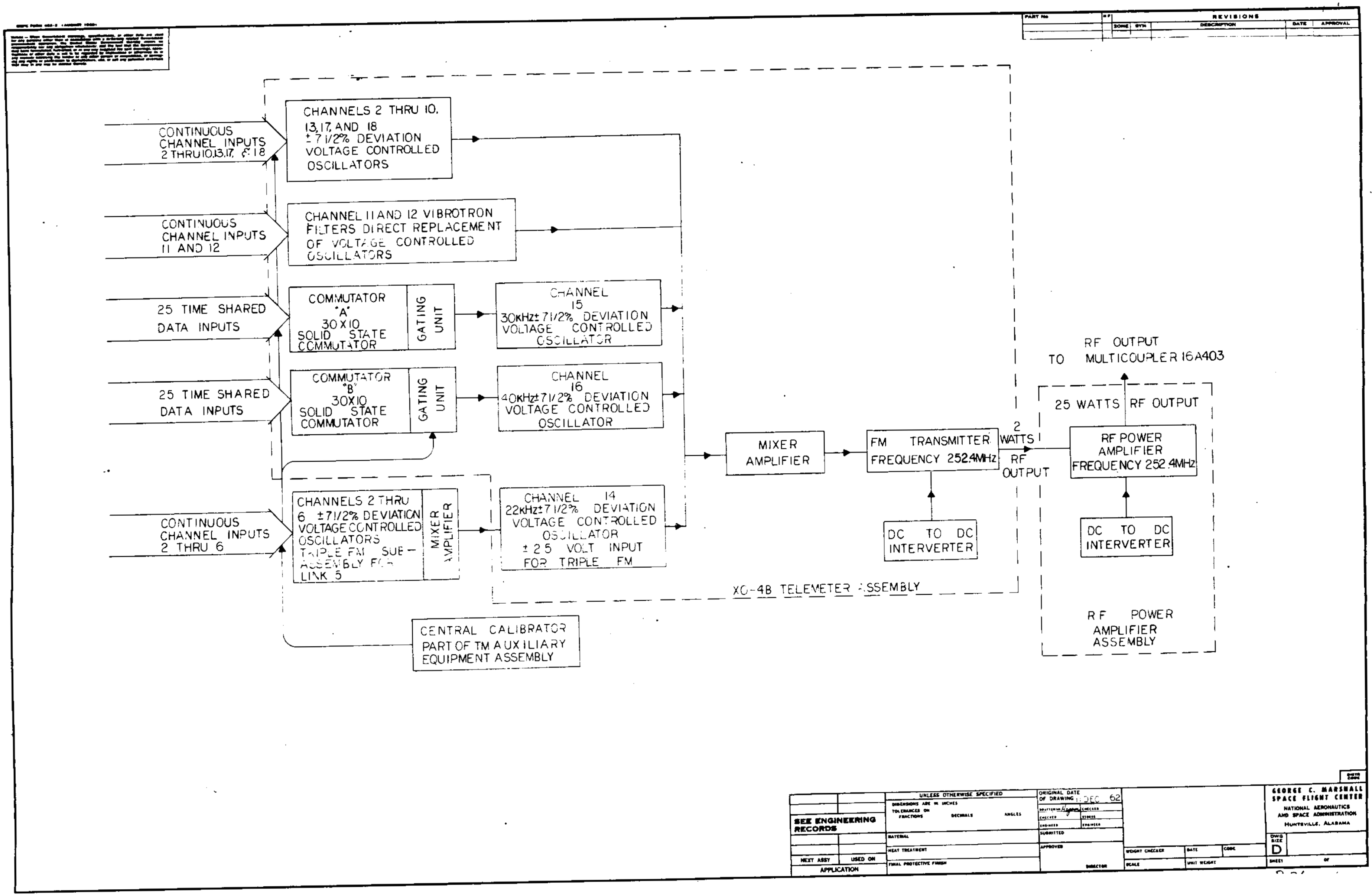

FIGURE 7. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 5

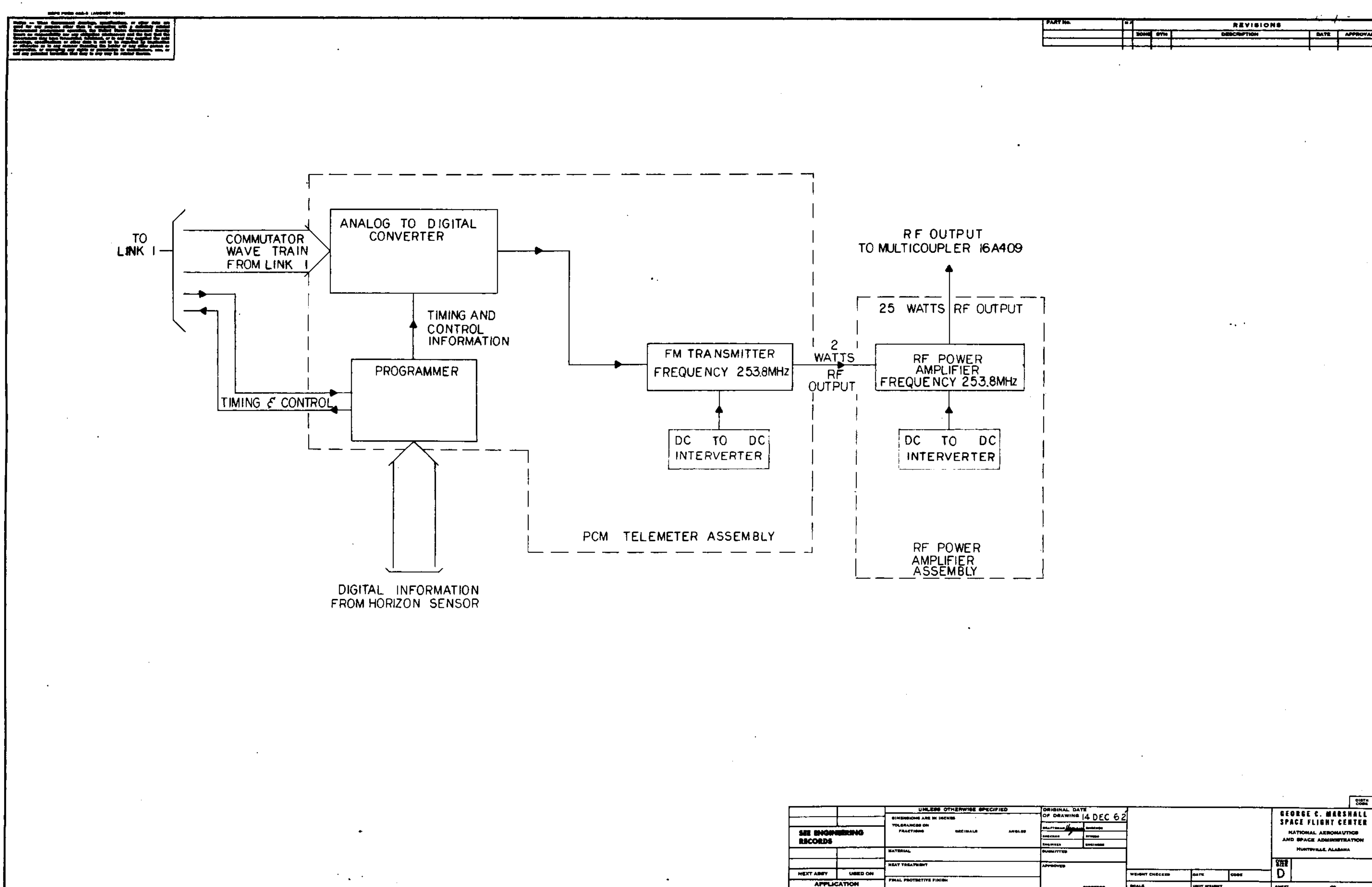

FIGURE 8. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 6

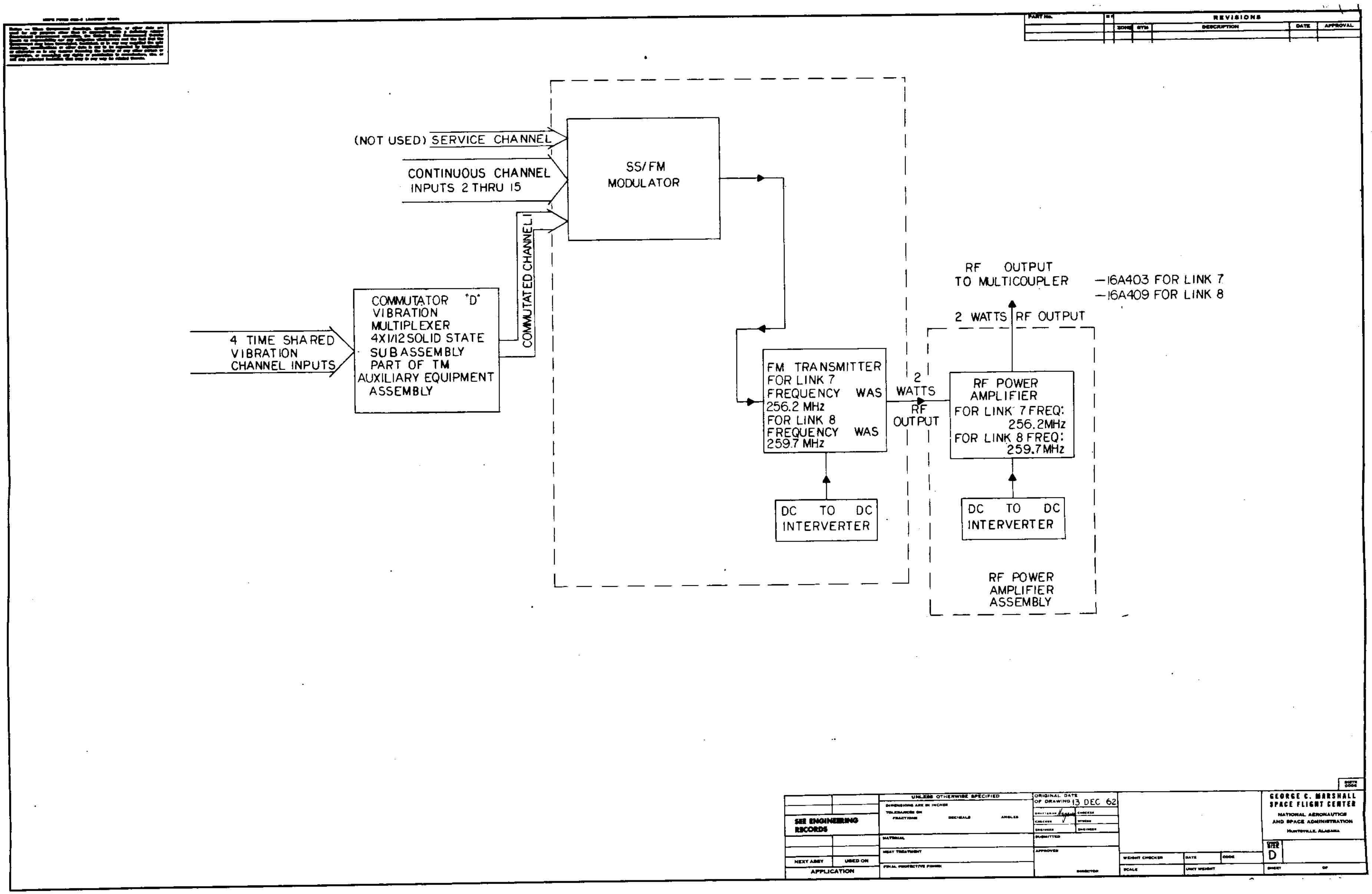

FIGURE 9. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINKS 7 AND 8

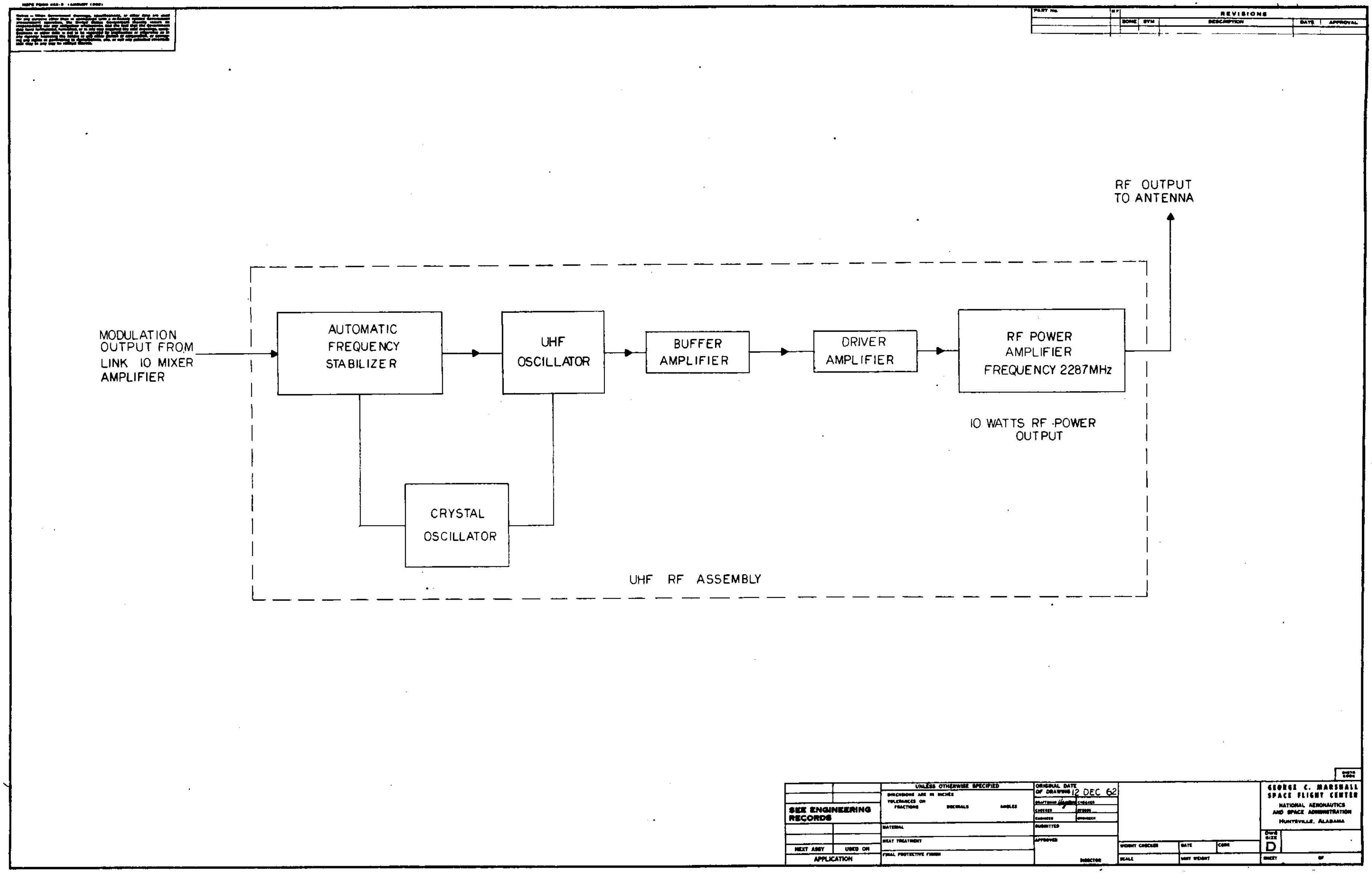

FIGURE 10. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 9

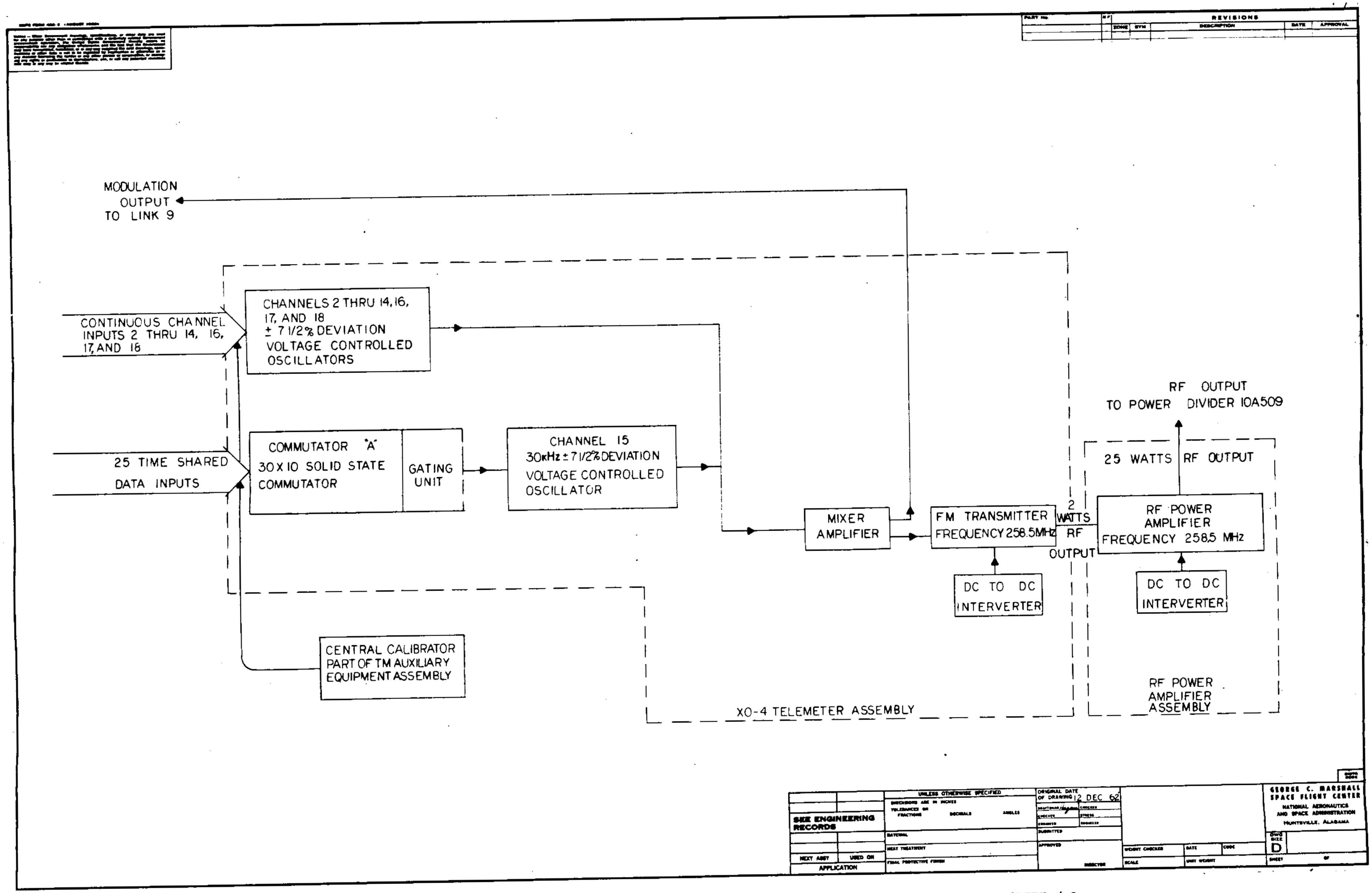

FIGURE 11. BLOCK DIAGRAM OF SATURN SA-3 TELEMETER LINK 10

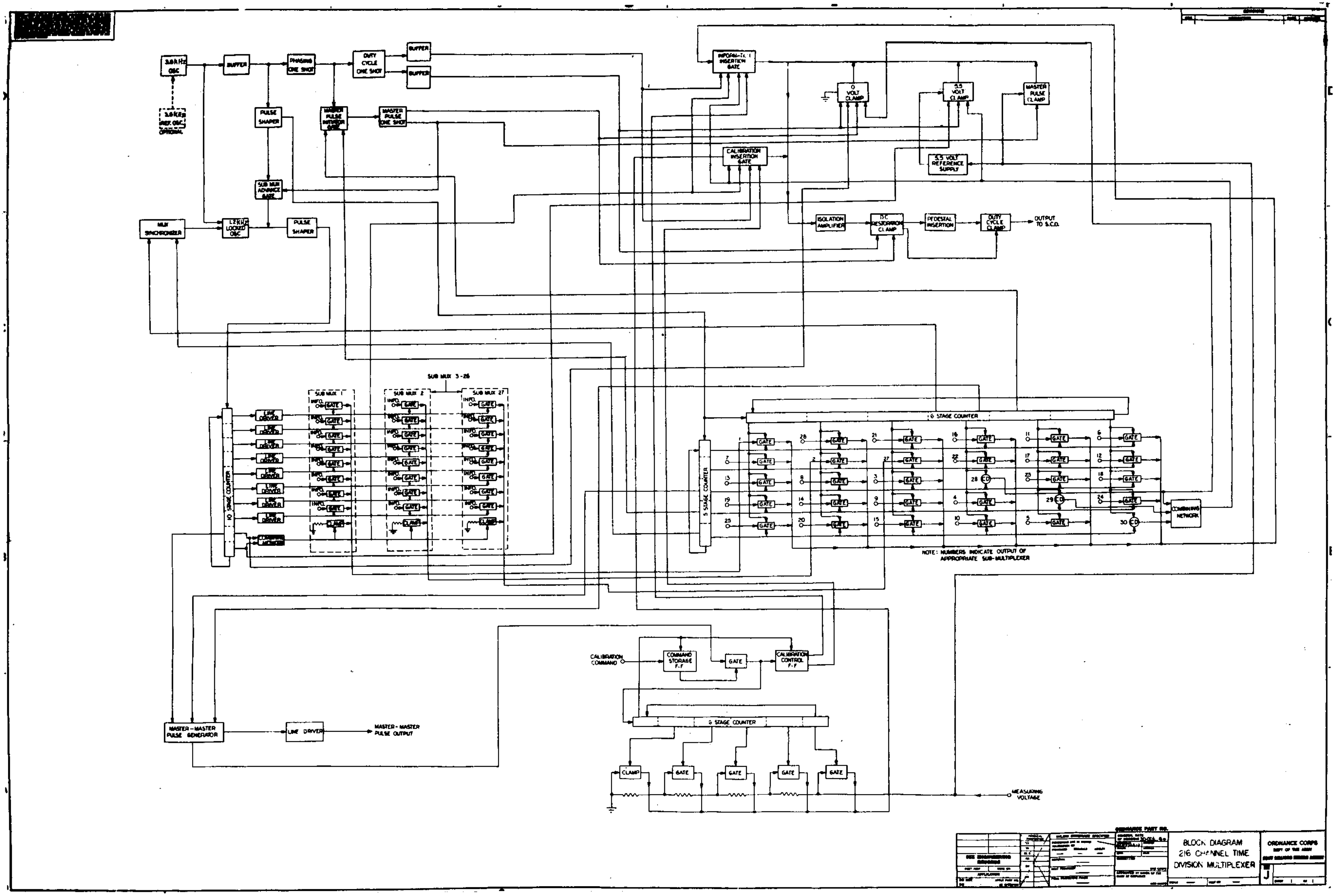

FIGURE 12. BLOCK DIAGRAM OF THE 216 TIME DIVISION MULTIPLEXER

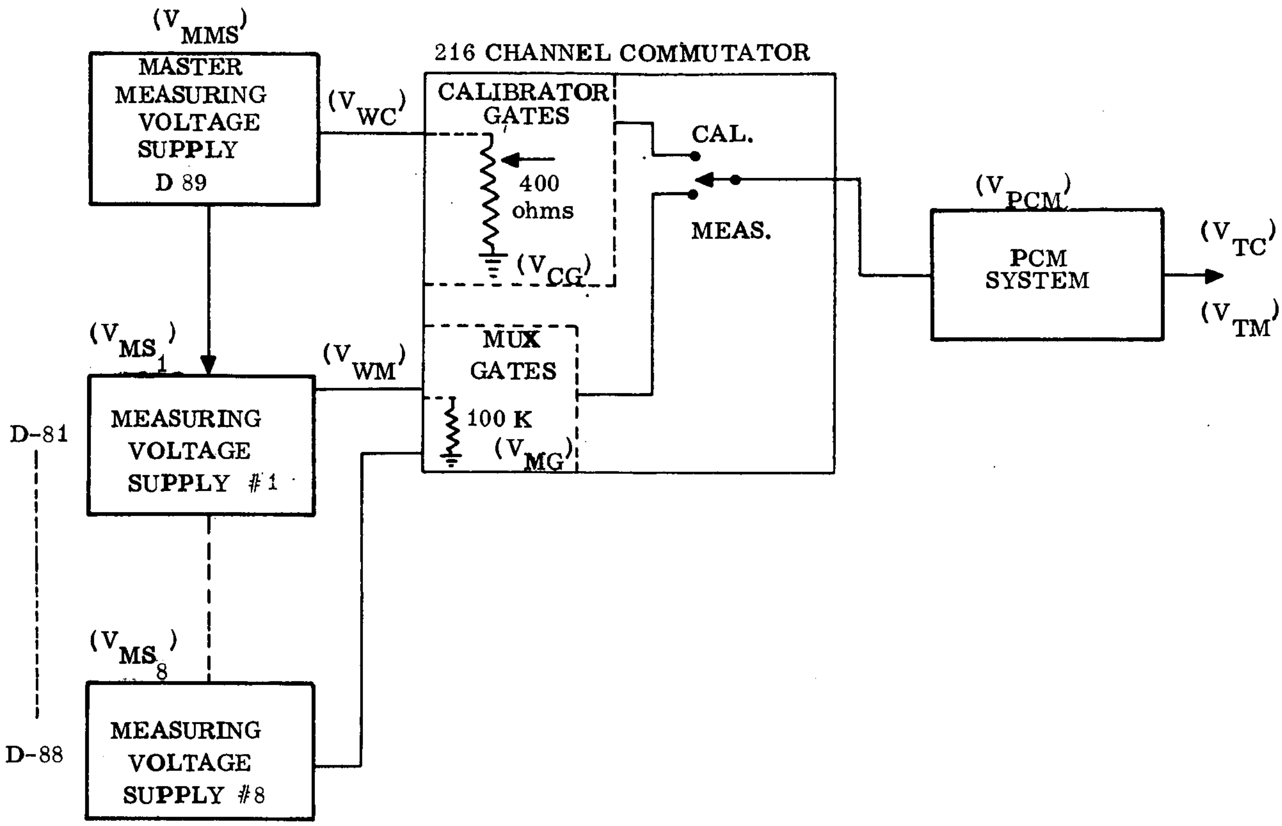

FIGURE 13. BLOCK DIAGRAM OF MEASURING VOLTAGE PATHS

APPROVAL

MTP-ASTR-I-63-17

SPACE VEHICLE SA-3, TELEMETRY SYSTEM

By

W. B. Threlkeld, Jr., and E. H. Reeves, Jr.

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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